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Site Selection for Limestone Paper Plant Using AHP-Monte Carlo Approach

H. Shahsavani[1*], S. Vafaie[2], R. Mikaeil[3]

1. Assistant Professor, Department of Mining, Faculty of Engineering, University of Kurdistan (UOK), Sanandaj, Iran
2. M.Sc. Student, Department of Mining, Faculty of Engineering, University of Kurdistan (UOK), Sanandaj, Iran
3. Assistant Professor, Department of Mining and Metallurgical Engineering, Urmia University of Technology, Urmia, Iran

Corresponding author: *h.shahsavani@uok.ac.ir*

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ABSTRACT

Paper played a crucial role in the history of the development of human society. Even in current times in the modern world, with Tablet, eBook readers and smart phones, the use of paper is still unavoidable. The wood needed for the production of the paper is provided by cutting down trees; hence, paper production has a cost to the environment. Recently, new technology has been developed which uses limestone instead of wood as the main material for paper production. This technology is environmentally friendly compared to the traditional paper-making technology. Choosing a suitable location for construction of such paper production plant based on different factors affecting paper quality is of great importance. To choose the desired location of such a plant, it is proposed to use a combination of Monte Carlo, and Analytical Hierarchic Process approaches. In this way, in the search area, there is a distribution of rates for each pixel instead of a single rate which allows determining the appropriate location for different confidence levels. The proposed method has been applied on Bijar, one of the cites of Kurdistan province in Iran, and a suitable location of the paper production plant is highlighted for various levels of confidence.

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1. Introduction

The fiber achieved from the tree wood is the main constituent of paper. The use of wood causes the demolition of forest resources, leading to environmental destruction. Recently, a new technology has been developed that uses limestone to produce paper and facilitates the protection of the environment to a large extent. The main ingredient of lime stone paper, so-called paper stone, is Calcium Carbonate merging with High-Density Polyethylene (HDPE).

An appropriate location selection for a paper plant construction is a very important factor in this industry. Such a convenient location is affected by several factors. If the plant is not built in the right place, it will cause irreparable damage. For instance, an economic downturn, closures and/or spending much money for moving the plant to a different place are some examples of the anticipated damage. Therefore, a great deal of care must be taken in selecting the plant locations.

A location selection for limestone paper plant has to be performed by considering a set of criteria and their relationships. If the criteria are to be considered individually, several selection methods can be offered. One of the main difficulties in decision-making is a large number of criteria with unequal weights [1]. Therefore, an assessment of the related importance or weights of all criteria is required for decision-making [2]. The Analytical Hierarchic Process (AHP) is developed by Saaty for decision-making in multi-criterion problems [3–5]. This method has been applied in different fields. For instance, economic [2,6], environment [7], safety [8], selection location of thermal power plant [9], analysis of the quality of electronic services [10], renewable energy plans [11], selection of a suitable underground mining excavation [12], Identifying Influential Segments from Word Co-occurrence Networks [13], Multi-tier sustainable global supplier selection [14], and even selection of a weapon are some instances [15] in which this decision-making approach has been utilized.

In the common AHP method, the weights of each criterion are obtained from an expert opinion. However, in many cases, the expert comments on the weights of criteria are different from one another. In such circumstances, the final weight is achieved by eliminating the outlier and averaging the remains. Hence, the effect of uncertainty on the weight of criteria is not clear in the final results.

The Monte Carlo modeling approach offers a solution to this problem. Recently, various applications of the Monte Carlo modeling approach have been introduced. For instance, extreme response predictions for nonlinear floating offshore structures [16], study on random walk and its application to solution of heat conduction equation [17] and Multispectral Monte Carlo radiative transfer simulation by the maximum cross-section method [18], radiation transfer in 3D non-gray medium [19], The simulation of the expectation of a stochastic quantity [20], are some examples of Monte Carlo applications.

Recently, a combination of AHP and Monte Carlo simulation has been developed to solve the non-deterministic problems [21–24].

In this paper, it is proposed to use a combination of the Monte Carlo and AHP methods. In this way, the uncertainty in weight of criteria is available in the final result. Indeed, for each alternative, there are thousands of scores that allows us to obtain the distribution of such scores for each criterion which make it possible to calculate the score of each alternative with different levels of confidence.

The combination of Monte Carlo and AHP has been used in a variety of contexts. For instance, flood susceptibility mapping [25], ranking dental quality attributes [24], selection of optimum mining method [21], Assessing Preferred Non-Point-Source Pollution Control Best Management Practices [26], The Risk Analysis of the Cost of Construction Project [27].

2. Monte Carlo method

The Monte Carlo is a simulation method for functions with multi-independent variables. These variables do not have an explicit amount but include distribution of amounts. By random sampling from variable distributions and assigning them to desired variables of the function, a response is obtained. This process is repeated many times, which enables us to achieve the distribution of responses and express it for the different confidence level. In general, Monte Carlo simulation can be used for phenomena with deterministic and non-deterministic variables and there is a specific relationship between them [28]. In summary: the Monte Carlo simulation is performed in six steps [21]:

Step 1: Prepare the probability distribution function for each deterministic variable, according to the experts' opinion

Step 2: Generate a random number between 0 and 1

Step 3: Determine the variable with respect to Steps 1 and 2

Step 4: Obtain the answer to the function in accordance with Step 3

Step 5: Repeat Steps 2, 3 and four several times

Step 6: Obtain the probability distribution function of answers

3. AHP method

The AHP method is a simple calculation approach based on the basic operation of matrices. The hierarchical analysis consists of three main steps:

Step 1: Making hierarchy

Step 2: Collecting data to obtain information to compare pairs of elements of the hierarchical structure

Step 3: Combining priorities for calculating the score of each alternative

The main drawbacks of the AHP method are [6,9,21,29–31].

- This method fails to determine the best alternative when the scores are very close.
- This method cannot resolve the uncertainty problem for the amount assigned to each criterion.
- The expert opinions about the weight of criterion have a great impact on final results.

The AHP-Monte Carlo approach proposed in this research has been able to largely overcome these problems.

4. AHP-Monte Carlo approach

The AHP-Monte Carlo method is a combination of Monte-Carlo simulation and AHP approach. The statistical analysis of the obtained results is the most important feature of the AHP-Monte Carlo method. Hence, each alternative not only has a score but also contains a probability distribution of the scores, which allows us to determine the score for a specified level of confidence. The advantages of the AHP-Monte Carlo method are:

- Opinions of all the experts are used to calculate the final results.
- It is possible to check the effect of the variance of experts' opinion on the final results.
- Provides the score and also the probability of that score for each alternative.

The AHP-Monte Carlo method steps are shown in the flowchart in Fig 1.

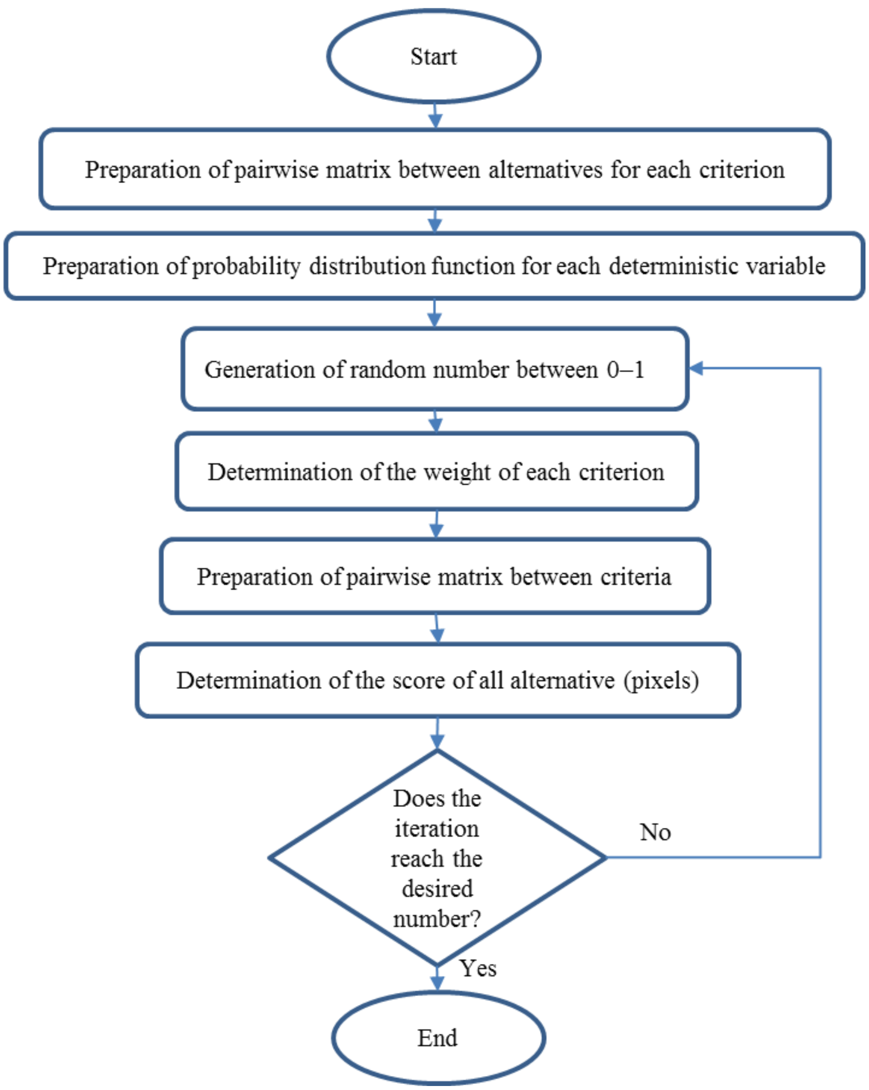


Fig. 1. Flowchart AHP-Monte Carlo method steps.

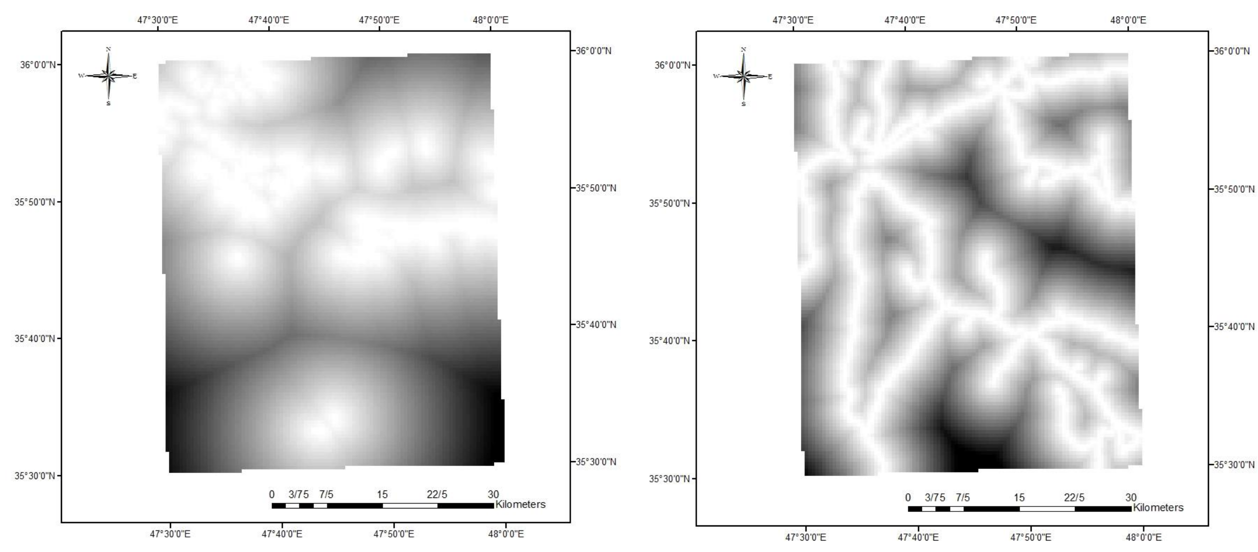
The number of iterations is arbitrary, but it must be repeated a sufficient number of times to obtain the probability distribution of each alternative score.

5. Implementation

Many factors affect the choice of site location of a limestone paper plant. In this paper. Such important criteria are the distance to the city, village, major faults, minor faults, main road, byroad distance, river, formations that contain limestone and finally the presence of limestone in such areas, which is totally nine items. It is worth mentioning due to limestone mineralization, seams and fractures, especially faults, play an important role. Wherever there are a failure and more faults, it is more prone to mineralization of limestone. Main faults are more associated with mineralization because they have more effect on the alteration of materials. As a result, more importantly, they are more important than the underlying faults. Also, In Iran, the main roads have better conditions, while byroads have major communication problems, and the main road is a better option than a subway road. The city and the village are the same. Villages have fewer facilities than the city. Hence it is possible to consider these criteria as independent criteria.

The map of each criterion is prepared with respect to the geological map of Bijar with a scale of 1:100000. Each map has 10696 pixels in 115 rows and 93 columns.

At the next step, the location of each criterion is determined on the maps. For example, the pixels on the main road have been determined, and weight one is assigned to such points. Away from these points, the weight of the pixel is reduced to 0. Finally, for each criterion, a map was made. In such maps, each pixel has a weight between 0 and 1; hence these are called normalized map. In Figure 2, a normalized map of prone limestone formation and main road has been depicted. The white and black parts of these maps have 1 and 0 weights respectively.

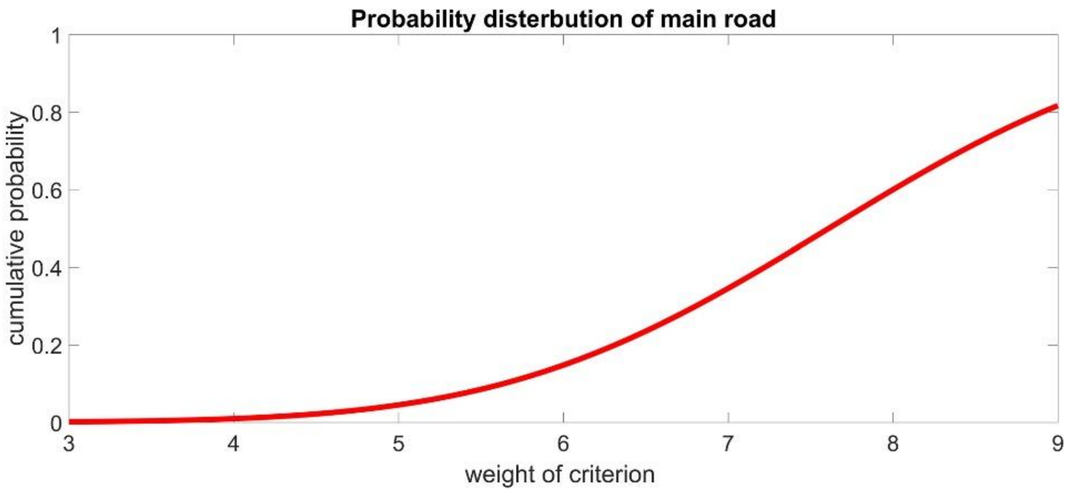


a) b)

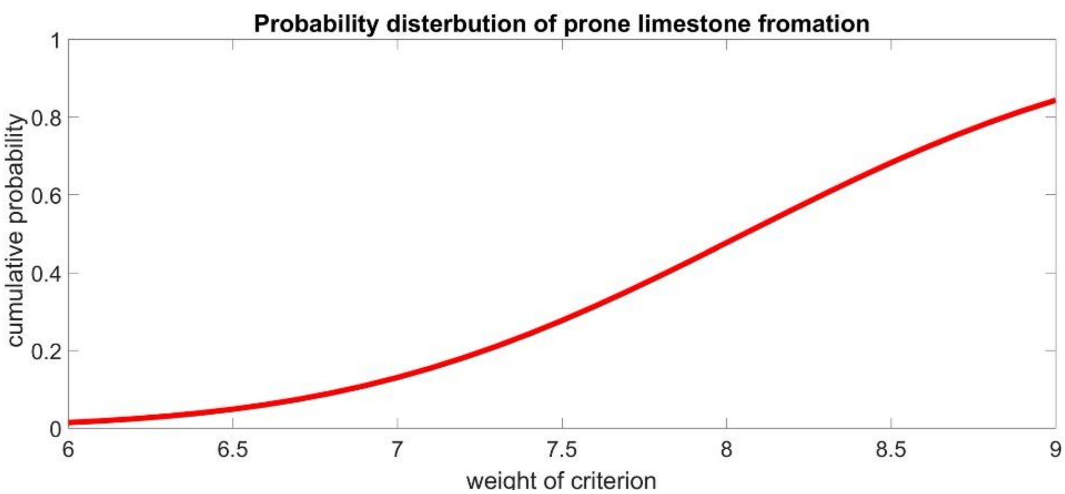
Fig. 2. A normalized map of a) prone limestone formation b) main road, the white parts have 1, and black parts have 0 weights.

Indeed, each pixel in the map is an alternative. Hence, the alternative pairwise matrix for each criterion has 10696 rows and 10696 columns. In other words, 10696 alternatives are available for selection of the site of limestone paper plant.

Once the expert opinions are obtained, the probability distribution of criterion would be ready. These distributions are illustrated in Figure 3 for two representative criteria: prone limestone formation and main roads.



a)



b)

Fig 3. The probability distribution of a) main roads criterion b) prone limestone formation.

Afterward, a random number between 0–1 is generated. Based on this random number and probability distribution, the weight of each criterion was obtained. Then, by using the AHP method, the score of each alternative (here pixel) was calculated. This process, i.e., the random sampling and the use of the AHP method for score determination, is repeated 10,000 times. Therefore, for each pixel, there are 10,000 scores, which allow us to obtain the probability distribution of these scores for each pixel. In Figure 4, the probability distribution of the scores of a pixel in the map is shown.

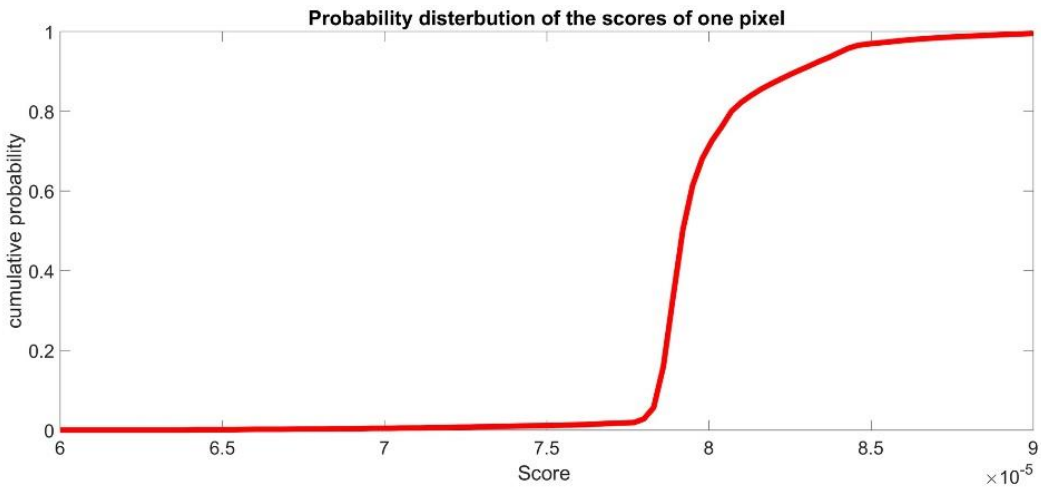
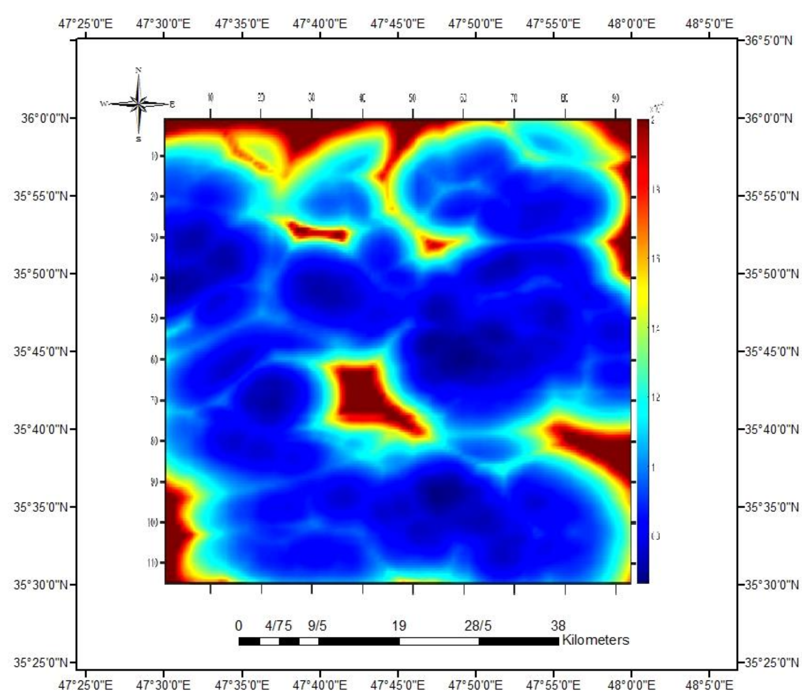
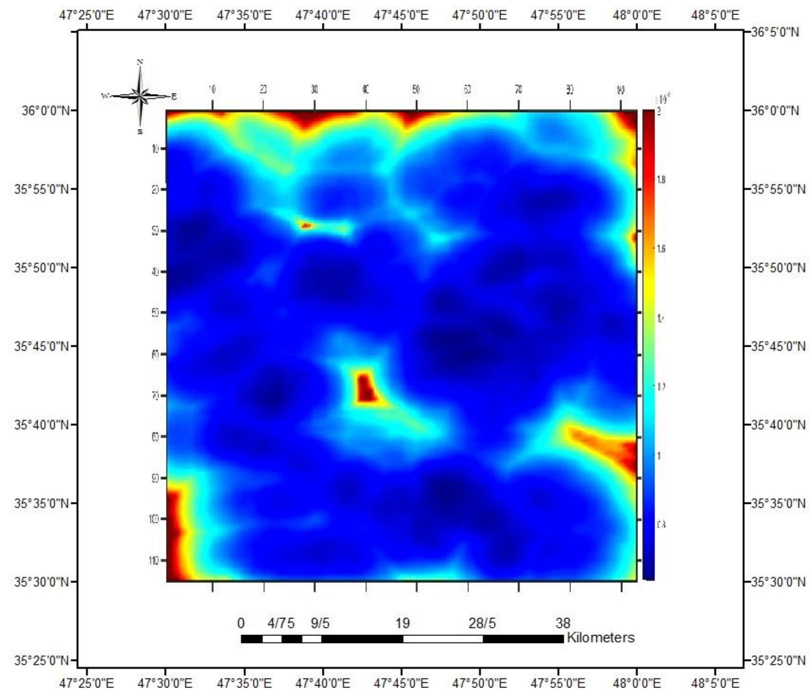


Fig 4. The probability distribution of a pixel of the map. This distribution has been obtained using a total of 10,000 samples (score).

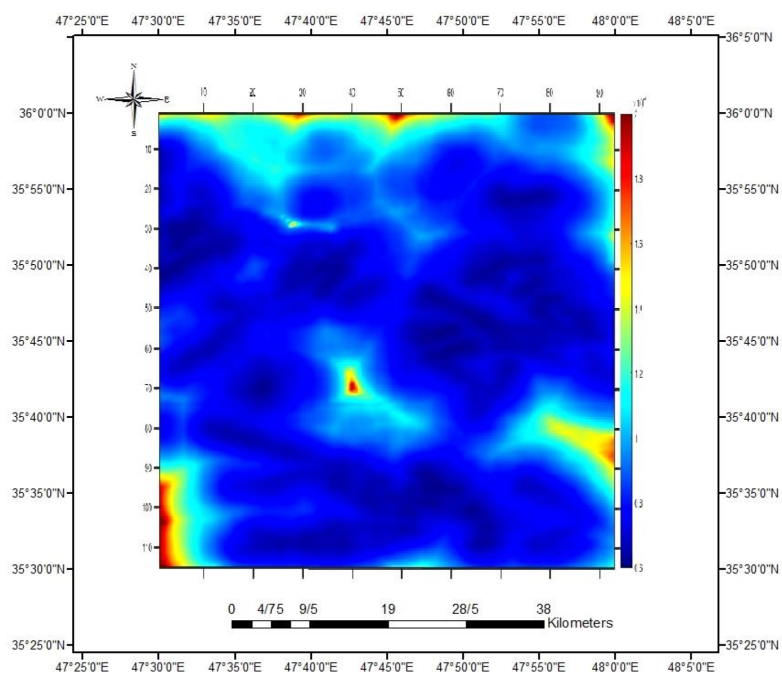
Once the probability distribution of the scores for each pixel of the map is obtained, it is possible to calculate the score of each pixel for different confidence levels. In Figure 5, a map of suitable sites for paper plant establishment has been depicted for 10, 50, and 90 percent of confidence level.



a)



b)



c)

Fig 5. Map of suitable sites for limestone paper plant establishment. a) suitable sites for 10 percent of confidence level b) suitable sites for 50 percent of confidence level c) suitable sites for 90 percent of confidence level.

6. Discussion

The AHP method fails to consider the deviation of the expert opinion on the score of each alternative. By a combination of AHP and Monte-Carlo (MAHP) now it is possible to assess the probability of the score of each alternative with respect to expert opinion. By applying this idea on a map by the assumption that each pixel of the map is an alternative the probability of the scores is obtained. In this way, the opinion of all expert is considered.

Once the probability of the scores for all pixel is calculated, it is possible to express the score with the different of confidence level. As it has been shown in figure 5 by increasing the confidence level the appropriate area becomes small and smaller and vice versa. With respect to the result of figure 5, the point at the center of the map is an appropriate location for the paper power plant.

7. Conclusion

Limestone paper production is a revolutionary advanced technology, one which reduces the associated pollution and environmental risks. Suitable site selection for plants has a great impact on the success of such projects. This selection is affected by several criteria. The weight of each criterion is determined by the answers to the question by experts. However, the weight discrepancy of the criteria has always been a problem. It proposed a combination of the AHP and Monte Carlo methods to overcome this problem. This combination allows us to have a large number of scores for each pixel of the search area, which, in turn, gives the score possibility for each pixel. The proposed method has been applied on the map of Bijar with a scale of 1:100000. Then, the suitable sites for different levels of confidence have been determined. As expected, by increasing the confidence level, the number of appropriate sites became fewer.

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